Response to G. Kampis "Complexity is Cue to the Mind"

Chaotic Itinerancy is a Key to Mental Diversity

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Abstract

Kampis proposed the study of chaotic itinerancy, pointing out its significance in domains of cognitive science and philosophy. He discovered in the concept of chaotic itinerancy the possibility for a new dynamical approach that elucidates mental states with a physical basis. This approach may therefore provide the means to go beyond the connectionist approach. In accordance with his theory, we here highlight three issues regarding chaotic itinerancy: transitory dynamics, diversity, and self-modifying system.

The main characteristics of chaotic itinerancy are summarized as follows (Kaneko and Tsuda 2001, 2003, Tsuda 2001), although not all characteristics are necessarily required:
(1) there appear a relatively large number of modes possessing neutral stability as well as definite stable and unstable modes;
(2) there appears a highly ordered but irregular temporal structure, and hence the appearance of history-dependent transitions;
(3) chaotic itinerancy differs from simply chaotic behavior in the sense that these transitions can be characterized as transitory dynamics through which the system moves between low-dimensional attractor ruins and high-dimensional chaotic states;
(4) the statistical convergence of physical quantities is absent or extremely weak;
(5) the system does not possess tracing properties.

There is a mathematical basis for each of the above-stated characteristics. In a system that possesses the pseudo-orbit tracing property, it is guaranteed that its mathematical

trajectories can be correctly traced in numerical simulations. Typical chaotic systems possess this property, but some chaotic systems do not. In such systems, it is not possible to properly trace each trajectory in simulations. This lack of the pseudo-orbit tracing property leads to another instability, which differs from orbital instability that chaotic systems inherently possess, that is, instability with regard to computation, description, and/or observation. Thus, contrary to the picture presented by Kampis, a factor for renewing a system itself exists even in conventional chaos, in principle. However, as Kampis correctly points out, this property is not enough to realize an actual renewal process. Even if such a property does not exist, it is possible to obtain precise statistical properties, which reflect the properties of an attractor as a whole. Actually, this attractor-tracing property exists even in conventional chaos. On the other hand, the statistical properties of chaotic itinerancy do not necessarily provide information about the overall attractor (Sauer 2000, 2003, Tsuda and Umemura 2003). Chaotic itinerancy thus appears to be a new type of dynamic behavior that goes beyond the attractor concept. It is thus seen that chaotic itinerancy can be considered a form of transitory dynamics that might appear to be ``non-stationary'' in short-time observations.

In dynamical systems exhibiting chaotic itinerancy, there come to exist transition rules between attractor ruins. The nature of these rules is determined by chaotic itinerancy itself. The dynamical orbit is attracted to the ruins, and in this situation, the number of effective degrees of freedom remain relatively small. Therefore the system can be described with only a few modes. While the system remains in such a space, other modes become activated. As a result, the system can no longer be confined in such a space. Because there are restricted regions that can act as exits, there are a number of selected orbits that can leave (Kaneko 1998). When an orbit leaves this space, the number of effective degrees of freedom increases, and there results a large diversity of states. After some time, the orbit is attracted to another ruin, where a different set of effective modes describe the system. In such a way, such dynamical systems exhibit history-dependent activity.

In the study of dynamic behavior in a neural network model with nearest-neighbor couplings, we recently identified a mechanism involved in chaotic transitions between synchronized and de-synchronized states (Tsuda, Fujii, Tadokoro, Yasuoka, and Yamaguti 2004). Such transitions have been observed in animal and human brains (Freeman 2004, Gray, Engel, Koenig, and Singer 1992, Lampl, Reichova, and Ferster 1999). This behavior appears to consist of chaotic itinerancy between attractor ruins

representing synchronization and de-synchronization states. It also appears that this behavior can be regarded as chaotic itinerancy between attractor ruins (which may be described by Milnor attractors), each consisting of an all-synchronization state, different kinds of metachronal waves, and large chaotic orbits. Furthermore, such chaotic itinerancy accompanies the organization and reorganization of dynamic cell assemblies. There are several examples that are believed to provide a link between physical behavior and the representation of mental states using chaotic itinerancy. These examples include dynamic memory (Tsuda, Koerner, and Shimizu 1987, Tsuda 1991, Tsuda 1992), episodic memory formation (Tsuda and Kuroda 2001), and category formation (Tsuda 2001). The use of chaotic itinerancy to study category formation might elucidate a typical feature of diversity expressed by chaotic itinerancy, as described by Kampis.

Category formation can be characterized by the following two kinds of ambivalence. We call the first kind identification and discrimination ambivalence. In this case, "similar" patterns, objects, and concepts must be classified in accordance with their similarity as belonging to the same group. Here, similarity can be represented by a certain metric. Yet, it must be possible to discriminate even similar patterns, objects, and concepts. The second kind, which we call invariance and variance ambivalence, appears especially in relation to learning over periods of time that are longer than those expected in the case of the first ambivalence. For stability of cognition, the invariance of categories is required, but to allow the learning process, a variance of classification, that is, a change of categories is necessary.

Our assertion is that chaotic itinerancy can represent the types of ambivalence described above, in principle. In typical chaotic itinerancy, the attractor ruins linked by chaotic transitory orbits do not necessarily constitute all the ruins, because of the dependence of statistical properties on the initial conditions. Some particular orbit linking several attractor ruins may form the largest category of series of events, i.e., an episode, with each attractor ruin representing a distinct event. This largest category consists of several sub-episodes, some of which are "similar" and some of which are different. Actually, we found such category formation in a Cantor code with chaotic itinerancy as inputs (Tsuda 2001, Tsuda and Kuroda 2001). This is possible, because chaotic itinerancy contains history-dependent information of a series of events (Kaneko 1998). This scheme of coding guarantees both identification and discrimination.

From the above findings, it is seen that chaotic itinerancy may be a key type of dynamic motion that can describe ever-changing behavior with stability, which all evolving systems should exhibit. This is nothing but an evolutionary system that Kampis describes as a self-modifying system (Kampis 1991). In contrast to the conventional concept of a system, accompanying to which a system consists of well-defined units, with each unit assumed to possess a definite function, we consider a self-modifying system to be a life system, in which a functional unit is formed via interactions between internal states of the system. Such a system is precisely that which we have considered a 'complex system' (Kaneko and Tsuda 2001).

There is sufficient evidence supporting such a specific structure of complex systems. Among others, cell differentiation and the organization of functional modules in the brain are typical examples. Every functional module in the brain, like the visual cortex, is connected to other modules in its living state, not only structurally but also functionally. In other words, functional modules are not ready-made but, rather, order-made. They are formed almost-simultaneously when a total system becomes functional. This type of formation brings about a difference between the responses of organized units in the cases that these units are isolated and are embedded in the system. Furthermore, such functional modules can vary in structure and function. A similar concept was proposed as the concept of components (Rosen 1991) and as a dynamic cell assembly (Marlsburg 1981, Fujii, Ito, Aihara, Ichinose, and Tsukada 1996).
These characteristics are those of ever-changing systems, which are typically described by chaotic itinerancy and may well be related to the flexible change of mental states.

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